



ISBN 978 3 900734 88 6

COMMISSION INTERNATIONALE DE L'ECLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

TECHNICAL REPORT

PRACTICAL METHODS FOR THE MEASUREMENT OF REFLECTANCE AND TRANSMITTANCE

CIE 130-1998

UDC: 535.345.1
535.312
535.361.1
535.361.2

Descriptor: Regular transmittance
Regular reflectance
Diffuse transmittance
Diffuse reflectance

THE INTERNATIONAL COMMISSION ON ILLUMINATION

The International Commission on Illumination (CIE) is an organisation devoted to international co-operation and exchange of information among its member countries on all matters relating to the art and science of lighting. Its membership consists of the National Committees in 39 countries and one geographical area and of 11 individual members.

The objectives of the CIE are :

1. To provide an international forum for the discussion of all matters relating to the science, technology and art in the fields of light and lighting and for the interchange of information in these fields between countries.
2. To develop basic standards and procedures of metrology in the fields of light and lighting.
3. To provide guidance in the application of principles and procedures in the development of international and national standards in the fields of light and lighting.
4. To prepare and publish standards, reports and other publications concerned with all matters relating to the science, technology and art in the fields of light and lighting.
5. To maintain liaison and technical interaction with other international organisations concerned with matters related to the science, technology, standardisation and art in the fields of light and lighting.

The work of the CIE is carried on by eight Divisions each with about 20 Technical Committees. This work covers subjects ranging from fundamental matters to all types of lighting applications. The standards and technical reports developed by these international Divisions of the CIE are accepted throughout the world.

A plenary session is held every four years at which the work of the Divisions and Technical Committees is reviewed, reported and plans are made for the future. The CIE is recognised as the authority on all aspects of light and lighting. As such it occupies an important position among international organisations.

LA COMMISSION INTERNATIONALE DE L'ECLAIRAGE

La Commission Internationale de l'Eclairage (CIE) est une organisation qui se donne pour but la coopération internationale et l'échange d'informations entre les Pays membres sur toutes les questions relatives à l'art et à la science de l'éclairage. Elle est composée de Comités Nationaux représentant 39 pays plus un territoire géographique, et de 11 membres individuels.

Les objectifs de la CIE sont :

1. De constituer un centre d'étude international pour toute matière relevant de la science, de la technologie et de l'art de la lumière et de l'éclairage et pour l'échange entre pays d'informations dans ces domaines.
2. D'élaborer des normes et des méthodes de base pour la métrologie dans les domaines de la lumière et de l'éclairage.
3. De donner des directives pour l'application des principes et des méthodes d'élaboration de normes internationales et nationales dans les domaines de la lumière et de l'éclairage.
4. De préparer et publier des normes, rapports et autres textes, concernant toutes matières relatives à la science, la technologie et l'art dans les domaines de la lumière et de l'éclairage.
5. De maintenir une liaison et une collaboration technique avec les autres organisations internationales concernées par des sujets relatifs à la science, la technologie, la normalisation et l'art dans les domaines de la lumière et de l'éclairage.

Les travaux de la CIE sont effectués par 8 Divisions, ayant chacune environ 20 Comités Techniques. Les sujets d'études s'étendent des questions fondamentales, à tous les types d'application de l'éclairage. Les normes et les rapports techniques élaborés par ces Divisions Internationales de la CIE sont reconnus dans le monde entier.

Tous les quatre ans, une Session plénière passe en revue le travail des Divisions et des Comités Techniques, en fait rapport et établit les projets de travaux pour l'avenir. La CIE est reconnue comme la plus haute autorité en ce qui concerne tous les aspects de la lumière et de l'éclairage. Elle occupe comme telle une position importante parmi les organisations internationales.

DIE INTERNATIONALE BELEUCHTUNGSKOMMISSION

Die Internationale Beleuchtungskommission (CIE) ist eine Organisation, die sich der internationalen Zusammenarbeit und dem Austausch von Informationen zwischen ihren Mitgliedsländern bezüglich der Kunst und Wissenschaft der Lichttechnik widmet. Die Mitgliedschaft besteht aus den Nationalen Komitees in 39 Ländern und einem geographischen Gebiet und aus 11 persönlichen Mitgliedern.

Die Ziele der CIE sind :

1. Ein internationaler Mittelpunkt für Diskussionen aller Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik und für den Informationsaustausch auf diesen Gebieten zwischen den einzelnen Ländern zu sein.
2. Grundnormen und Verfahren der Lichttechnik auf dem Gebiet der Lichttechnik zu entwickeln.
3. Richtlinien für die Anwendung von Prinzipien und Vorgängen in der Entwicklung internationaler und nationaler Normen auf dem Gebiet der Lichttechnik zu erstellen.
4. Normen, Berichte und andere Publikationen zu erstellen und zu veröffentlichen, die alle Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik betreffen.
5. Liaison und technische Zusammenarbeit mit anderen internationalen Organisationen zu unterhalten, die mit Fragen der Wissenschaft, Technik, Normung und Kunst auf dem Gebiet der Lichttechnik zu tun haben.

Die Arbeit der CIE wird in 8 Divisionen, jede mit etwa 20 Technischen Komitees, geleistet. Diese Arbeit betrifft Gebiete mit grundlegendem Inhalt bis zu allen Arten der Lichtenwendung. Die Normen und Technischen Berichte, die von diesen internationalen zusammengesetzten Divisionen ausgearbeitet werden, sind von der ganzen Welt anerkannt.

Tagungen werden alle vier Jahre abgehalten, in der die Arbeiten der Divisionen überprüft und berichtet und neue Pläne für die Zukunft ausgearbeitet werden. Die CIE wird als höchste Autorität für alle Aspekte des Lichtes und der Beleuchtung angesehen. Auf diese Weise unterhält sie eine bedeutende Stellung unter den internationalen Organisationen.

Published by the

COMMISSION INTERNATIONALE DE L'ECLAIRAGE
CIE Central Bureau
Kegelgasse 27, A-1030 Vienna, AUSTRIA
Tel: +43(01)714 31 87 0, Fax: +43(01)714 31 87 18
e-mail: ciecb@cie.co.at
WWW: <http://www.cie.co.at/>



ISBN 978 3 900 734 88 6

COMMISSION INTERNATIONALE DE L'ECLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

TECHNICAL REPORT

PRACTICAL METHODS FOR THE MEASUREMENT OF REFLECTANCE AND TRANSMITTANCE

CIE 130-1998

UDC: 535.345.1
535.312
535.361.1
535.361.2

Descriptor: Regular transmittance
Regular reflectance
Diffuse transmittance
Diffuse reflectance

This Technical Report has been prepared by CIE Technical Committee 2-14 of Division 2 "Physical measurement of light and radiation" and has been approved by the Board of Administration of the Commission Internationale de l'Eclairage for study and application. The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by the CIE membership and other interested parties. It should be noted, however, that the status of this document is advisory and not mandatory. The latest CIE proceedings or CIE NEWS should be consulted regarding possible subsequent amendments.

Ce rapport technique a été préparé par le Comité Technique CIE 2-14 de la Division 2 "Mesures physiques de la lumière et des radiations" et a été approuvé par le Bureau d'Administration de la Commission Internationale de l'Eclairage, pour étude et application. Le document traite des connaissances courantes et de l'expérience dans le domaine spécifique indiqué de la lumière et de l'éclairage, et il est établi pour l'usage des membres de la CIE et autres groupements intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire. Pour connaître d'éventuels amendements, consulter les plus récents comptes rendus de la CIE ou le CIE NEWS.

Dieser Technische Bericht ist vom CIE Technischen Komitee 2-14 der Division 2 "Physikalische Messungen von Licht und Strahlung" ausgearbeitet und vom Vorstand der Commission Internationale de l'Eclairage gebilligt worden. Das Dokument berichtet über den derzeitigen Stand des Wissens und Erfahrung in dem behandelten Gebiet von Licht und Beleuchtung; es ist zur Verwendung durch CIE-Mitglieder und durch andere Interessierte bestimmt. Es sollte jedoch beachtet werden, daß das Dokument keine Empfehlung und keine Vorschrift ist. Die neuesten CIE-Tagungsberichte oder das CIE NEWS sollten im Hinblick auf mögliche spätere Änderungen zu Rate gezogen werden.

Any mention of organisations or products does not imply endorsement by the CIE. Whilst every care has been taken in the compilation of this lists, up to the time of going to press, these may not be comprehensive.

Toute mention d'organisme ou de produit n'implique pas une préférence de la CIE. Malgré le soin apporté à la compilation de tous les documents jusqu'à la mise sous presse, ce travail ne saurait être exhaustif.

Die Erwähnung von Organisationen oder Erzeugnissen bedeutet keine Billigung durch die CIE. Obgleich große Sorgfalt bei der Erstellung von Verzeichnissen bis zum Zeitpunkt der Drucklegung angewandt wurde, ist es möglich, daß diese nicht vollständig sind.

This guide is dedicated to the memory of the late Professor Jürgen Krochmann.

The following members of TC 2-14 "Measurement of Reflectance and Transmittance, including Turbid Media" took part in the preparation of this Technical Report. The TC comes under CIE Division 2 "Physical Measurement of Light and Radiation".

J. Krochmann* (Chairman)	Germany
P. Polato (Chairman)	Italy
F. Geotti-Bianchini	Italy
D. Gundlach	Germany
J.J. Hsia	U.S.A.
L. Morren	Belgium
H. Terstiege	Germany
J. Verrill	Great Britain

* Professor J. Krochmann passed away on 27 January 1991.

Table of Contents

Summary	VII
Résumé	VII
Zusammenfassung	VIII
1. Scope.....	1
2. Definitions.....	1
2.1 Processes	1
2.1.1 Reflection	1
2.1.2 Transmission	1
2.1.3 Absorption	2
2.1.4 Regular reflection; specular reflection (Regular transmission; direct transmission)	2
2.1.5 Diffuse reflection (Diffuse transmission)	2
2.1.6 Mixed reflection (Mixed transmission).....	2
2.1.7 Isotropic diffuse reflection (Isotropic diffuse transmission)	2
2.1.8 Perfect reflecting diffuser (Perfect transmitting diffuser).....	2
2.1.9 Translucent medium.....	2
2.2 Characteristics	2
2.2.1 Reflectance (ρ) (Transmittance (τ))	2
2.2.2 Regular reflectance (ρ_r) (Regular transmittance (τ_r)).....	2
2.2.3 Diffuse reflectance (ρ_d) (Diffuse transmittance (τ_d)).....	2
2.2.4 Radiance factor/Luminance factor (β).....	3
2.2.5 Radiance/Luminance coefficient (q).....	3
2.2.6 Absorptance (α)	3
3. Parameters affecting the characteristics	3
3.1 Spectral parameters.....	3
3.1.1 Spectral composition of the incident radiation	3
3.1.2 Integral characteristics	4
3.2 Geometric conditions	4
3.3 Thin and thick translucent samples	6
3.4 Other parameters.....	7
4. Measurement principles	7
4.1 Absolute and relative methods	7
4.2 Spectral and integral characteristics	7
4.2.1 Spectral method	7
4.2.2 Integral method	7
4.2.3 Photometer, radiometer, spectroradiometer	8
4.3 Spatial evaluation.....	8
4.3.1 Goniometer/monophotometers.....	8
4.3.2 Practical methods	8
4.3.2.1 Methods using an integrating sphere	8
4.3.2.2 Directional methods	8
5. Measuring equipment	9
5.1 Components.....	9
5.2 Equipment for irradiation.....	9
5.2.1 Single and double beam	9
5.2.2 Geometric conditions	10
5.2.3 Spectral conditions	10
5.2.4 Polarization.....	10
5.2.5 Lamps.....	11
5.3 Equipment for detection	11
5.3.1 Irradiance/illuminance and radiance/luminance measurement	11
5.3.2 Radiometer/photometer head	11
5.3.3 Radiometer/photometer	12
5.3.4 Data recording.....	12
5.4 Monochromator.....	12
6. Integrating sphere.....	13

6.1	Measurement principles	13
6.2	Sphere theory	13
6.3	Substitution and comparison methods	14
6.4	Sphere coating	14
6.5	Sphere geometry	15
6.5.1	Diameters of the sphere and sample port	15
6.5.2	Ports	16
6.5.3	Radiometer/photometer head	18
6.5.3.1	Irradiance/illuminance measurement	18
6.5.3.2	Radiance/luminance measurement	19
6.5.4	Auxiliary lamp/auxiliary screen	19
6.5.5	Additional observations on sphere geometry	20
7.	Measurement of reflection characteristics using a sphere radiometer/photometer	21
7.1	Reflectance for directionally incident radiation	21
7.1.1	Introduction	21
7.1.2	Equipment for irradiation	21
7.1.3	Sphere geometry	21
7.1.3.1	Thin samples	21
7.1.3.1.1	Near-normal incidence	21
7.1.3.1.2	Other angles of incidence	22
7.1.3.2	Thick translucent samples	22
7.1.3.2.1	Near normal incidence	22
7.1.3.2.2	Other angles of incidence	22
7.1.4	Reflectance standards	23
7.1.5	Measurements and calculations	24
7.1.5.1	Thin samples	24
7.1.5.2	Thick translucent samples	24
7.1.6	Corrections in the case of mixed reflection	25
7.2	Diffuse reflectance	26
7.2.1	Samples with diffuse reflection only	26
7.2.2	Samples with mixed reflection	26
7.2.3	Diffuse reflectance standards	26
7.2.4	Measurements and calculations	27
7.2.4.1	Thin samples	27
7.2.4.2	Thick translucent samples	28
7.3	Reflectance for hemispherical radiation	28
7.3.1	Surface reflecting materials	28
7.3.1.1	Integrating sphere method	28
7.3.1.2	Diffuse reflectance standards	30
7.3.1.3	Measurements and calculations	30
7.3.2	Thick translucent samples	30
7.3.2.1	Principle	30
7.3.2.2	Measurements and calculations	30
8.	Measurement of transmission characteristics using a sphere radiometer/photometer	31
8.1	Transmittance for directionally incident radiation	31
8.1.1	Absolute methods	31
8.1.2	Integrating sphere method	31
8.1.2.1	Sphere with small sample port	31
8.1.2.2	Sphere with large sample port	32
8.1.2.3	Measurement of transmittance as a function of the angle of incidence	33
8.1.3	Transmittance standards	33
8.1.4	Measurements and calculations	34
8.1.4.1	Small sample port	34
8.1.4.2	Large sample port	34
8.1.5	Corrections in the case of mixed transmission	35
8.2	Diffuse transmittance	37
8.2.1	Samples with diffuse transmission only	37
8.2.2	Samples with mixed transmission	37

8.2.3	Measurements and calculations	37
8.3	Transmittance for hemispherical irradiation	38
8.3.1	Equipment for irradiation	38
8.3.2	Integrating sphere method	39
8.3.3	Measurements and calculations	39
8.3.4	Calculation of τ_{diff} from measured values of $\tau(\varepsilon)$	40
9.	Measurement of regular reflectance	41
9.1	Samples with regular reflectance only	41
9.1.1	Integrating sphere method	41
9.1.2	Illuminance ratio method	41
9.1.2.1	Absolute method	41
9.1.2.1.1	Method with double reflection (V-W method)	41
9.1.2.1.2	Goniometric method	42
9.1.2.2	Relative method	43
9.2	Samples with mixed reflection	45
9.2.1	Luminance ratio method	45
9.2.1.1	Relative method	45
9.2.1.2	Goniometric method	45
9.2.2	Integrating sphere method	45
10.	Measurement of regular transmittance	46
10.1	Samples with regular transmittance only	46
10.1.1	Integrating sphere method	46
10.1.2	Illuminance ratio method	46
10.2	Samples with mixed transmittance	47
10.2.1	Luminance ratio method	47
10.2.2	Integrating sphere method	48
11.	Measurement of absorptance	48
11.1	4π method	48
11.2	Calculation from reflectance and transmittance	49
12.	Measurement of radiance/luminance factor and radiance/luminance coefficient	49
12.1	Radiance/luminance factor	49
12.1.1	Measurement geometry	49
12.1.2	Measurement with directional irradiation and observation	50
12.1.3	Measurement with diffuse irradiation and normal observation	51
12.1.4	Standards for radiance/luminance factor	52
12.2	Radiance/luminance coefficient	52
13.	Sources of error and correction	52
13.1	General	52
13.2	Absolute and relative methods	52
13.3	Integral or spectral determinations	53
13.3.1	Possible sources of error in detectors	53
13.3.2	Possible additional sources of error with integral detectors	53
13.3.3	Possible additional sources of error with spectroradiometers	54
13.4	Geometrical considerations	54
13.4.1	Methods using an integrating sphere	54
13.4.2	Methods without an integrating sphere	55
14.	Characterization of the measuring equipment	55
14.1	Measurable quantities and required reference materials	55
14.2	Equipment for irradiation	55
14.2.1	Monochromator	56
14.3	Detector	56
14.4	Integrating sphere	56
14.5	Detector	56
14.6	Further information	56
15.	Bibliography	57

PRACTICAL METHODS FOR THE MEASUREMENT OF REFLECTANCE AND TRANSMITTANCE

SUMMARY

The characteristics of materials related to their reflection and transmission properties are defined in accordance with the International Lighting Vocabulary and other relevant CIE publications.

The parameters affecting these characteristics and the principles of measurement involved, which are the same whether the measurement is made in terms of spectral or weighted (e.g. luminous) characteristics, are specified.

Methods, using an integrating sphere, are recommended for the measurement of

- reflectance for directional ρ , $\rho(\varepsilon)$ and hemispherical ρ_{dif} incidence of radiation,
- diffuse reflectance ρ_{d} ,
- transmittance for directional τ , $\tau(\varepsilon)$ and hemispherical τ_{dif} incidence of radiation,
- diffuse transmittance τ_{d} .

Specific methods are also recommended for the measurement of

- regular reflectance ρ_{r} ,
- regular transmittance τ_{r} ,
- radiance/luminance factor β (radiance/luminance coefficient).

The absorptance α can either be measured directly or calculated from the measured values of reflectance and transmittance. Both procedures are described.

The principal measurement errors are examined and, where possible, methods for their elimination indicated.

METHODES PRATIQUES DE MESURE DES FACTEURS DE REFLEXION ET DE TRANSMISSION

RESUME

Les caractéristiques des matériaux qui se réfèrent à leurs propriétés de réflexion et de transmission des rayonnements optiques sont définies en conformité avec le Vocabulaire International de l'Éclairage et autres publications de la CIE sur le même sujet.

Les paramètres pouvant affecter les caractéristiques susdites et les principes de mesure sont spécifiés, ces principes étant les mêmes qu'il s'agisse de mesures de caractéristiques spectrales ou intégrales (lumineuses par exemple).

Des méthodes de mesure faisant usage d'une sphère intégratrice sont recommandées pour les déterminations

- du facteur de réflexion sous incidence directionnelle ρ , $\rho(\varepsilon)$ et hémisphériques ρ_{dif} ,
- du facteur de réflexion diffuse ρ_{d} ,
- du facteur de transmission sous incidence directionnelle τ , $\tau(\varepsilon)$ et hémisphériques τ_{dif} ,
- du facteur de transmission diffuse τ_{d} .

Des méthodes de mesure particulières sont recommandées pour les déterminations

- du facteur de réflexion régulière ρ_{r} ,
- du facteur de transmission régulière τ_{r} ,
- du facteur de luminance β (ou du coefficient de luminance q), ces grandeurs pouvant être énergétiques ou lumineuses.

Le facteur d'absorption α peut être mesuré directement ou calculé à partir des mesures des facteurs de réflexion et de transmission. Les deux procédures sont décrites.

Les erreurs de mesure les plus importantes et, dans la mesure du possible, des méthodes pour les éliminer, sont indiquées.

PRAKTISCHE METHODEN FÜR REFLEXIONS- UND TRANSMISSIONSMESSUNGEN

ZUSAMMENFASSUNG

Die Eigenschaften von Materialien in bezug auf ihre Reflexion und Transmission werden in Übereinstimmung mit dem Internationalen Wörterbuch der Lichttechnik und den entsprechenden CIE Publikationen definiert.

Es werden die Parameter, die diese Eigenschaften und Meßverfahren beeinflussen, angegeben, wobei die Verfahren zur Messung der spektralen und integralen (z. B. lichttechnischen) Eigenschaften gleich sind.

Meßmethoden, die eine Ulbricht-Kugel benutzen, werden empfohlen für

- Reflexionsgrad bei gerichtetem, ρ , $\rho(\varepsilon)$ und diffusem ρ_{dif} Strahlungseinfall,
- Grad der gestreuten Reflexion ρ_{d} ,
- Transmissionsgrad bei gerichtetem τ , $\tau(\varepsilon)$ und diffusem Strahlungseinfall,
- Grad der diffusen Transmission τ_{d} .

Spezielle Meßmethoden werden empfohlen für

- Grad der gerichteten Reflexion ρ_{r} ,
- Grad der gerichteten Transmission τ_{r} ,
- Strahldichte/Leuchtdichtefaktor β (Strahldichte/Leuchtdichtekoeffizient q).

Der Absorptionsgrad α kann entweder direkt gemessen werden oder aus den gemessenen Reflexions- und Transmissionsgraden berechnet werden. Beide Verfahren werden beschrieben.

Es werden auch die häufigsten Meßfehler und, so weit wie möglich, Methoden zu ihrer Beseitigung angeführt.

1. SCOPE

The CIE has published four Technical Reports which are basic documents for this Publication:

- International Lighting Vocabulary [1];
- Radiometric and Photometric Characteristics of Materials and their Measurement [2];
- Absolute Methods for Reflection Measurements [3];
- A Review of Publications on Properties and Reflection Values of Material Reflection Standards [4].

The reflection and transmission properties of materials in the wavelength range of optical radiation, particularly light, are important in many fields. This report deals mainly with the wavelength range $200 \text{ nm} < \lambda < 3\,000 \text{ nm}$. These properties are characterized by reflectance and transmittance with their regular and diffuse components, and radiance/luminance factor.

Different methods are described in the literature for the measurement of these characteristics and the results may differ according to the method used. It is, therefore, necessary to standardize one or more methods for the measurement of each defined quantity, designed to keep systematic errors as small as possible. This is the only way to ensure that the results of measurements, obtained with different instruments are comparable.

This CIE Technical Report sets out to define recommended methods for measuring the most important characteristics of reflection and transmission in industrial laboratories and to describe both the measurement geometry and the radiometric/photometric specification of the equipment used for irradiation and detection.

Absolute measurements of diffuse reflectance and measurements of the gonioradiometric/goniophotometric properties of materials are outside the scope of this publication. They are the subject of the work of other CIE Technical Committees.

Measurements on retroreflecting materials are also not treated here [5] and only a few brief notes, for guidance, are given on luminescent materials [2].

2. DEFINITIONS

The definitions relating to materials which are given in this Technical Report apply to optical radiation and particularly to visible radiation. The characteristics used for the description of these properties are generally expressed in terms of radiant, luminous or spectral quantities, but can also relate to other spectral weighting functions (see 3.1.2).

The definitions given here are taken from the International Lighting Vocabulary [1]. Where additional explanatory notes not in the ILV have been added, these are indicated by an asterisk *.

2.1 Processes

2.1.1 Reflection

Process by which radiation is returned by a surface or a medium, without change of frequency of its monochromatic components.

Note 1: Part of the radiation falling on a medium is reflected at the surface of the medium (surface reflection); another part may be scattered back from the interior of the medium (volume reflection).

Note 2: The frequency is unchanged only if there is no Doppler effect due to the motion of the materials from which the radiation is returned.

2.1.2 Transmission

Passage of radiation through a medium without change of frequency of its monochromatic components.